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EXAMINER'S AMENDMENT

An examiner's amendment to the record appears below. Should the changes and/or additions be unacceptable to applicant, an amendment may be filed as provided by 37 CFR 1.312. To ensure consideration of such an amendment, it MUST be submitted no later than the payment of the issue fee.

Authorization for this examiner's amendment was given in a telephone interview with Willard Jones on 2-22-2005.

The application has been amended as follows: In claim 1, lines 14,16 and 20, after "tilt" add --achieved during use--.

In claim 29, lines 13,16 and 20, after "tilt" add --achieved during use--.

In claim 30, lines 15,18 and 20, after "tilt" add --achieved during use--.

In claim 31, lines 21,24 and 28, after "tilt" add --achieved during use--.

Applicant is requested to resubmit the foreign priority document since it is not found in the file.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to William C Doerrler whose telephone number is (571) 272-4807. The examiner can normally be reached on Monday-Friday 6:30-4:30.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Denise Esquivel can be reached on (571) 272-4808. The fax phone number for the organization where this application or proceeding is assigned is 703-872-9306.

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Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. Patent application No. Demande de brevet n°

02255310.1

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

R C van Dijk

Anmeldung Nr:
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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

A liquid distributor

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A LIQUID DISTRIBUTOR

The present invention relates to a liquid distributor and in particular, but not necessarily limited to, a liquid distributor for distributing a liquid substantially uniformly across a liquid-vapour separation column located on an off-shore floating platform such as a ship.

Liquid distributors are used to distribute liquid uniformly over an area. Uniform distribution is important for efficient separation, especially if the separation is thermodynamically difficult.

By way of an example, liquid distributors are used to uniformly distribute a cryogenic liquid over the packing in the cryogenic distillation column of an air separation unit (or "ASU"). Uniform distribution is ideal. However, this is very difficult to achieve in practice and, thus, most commercial column packings are able to redistribute the liquid to some extent if the distribution is not uniform. Therefore, in most commercial applications, some non-uniformity of liquid distribution is acceptable.

In the prior art, there are two main types of liquid distributor, an open (e.g. channel) distributor and a closed (e.g. pipe) distributor. In the open distributor, the liquid is usually distributed under gravity via apertures (normally holes) located in the bottom of a series of open channels. The liquid is in contact with the surrounding vapour and, thus, the distributor cannot be pressurised. The closed distributor is usually made from pipes. The liquid is not in contact with the surrounding vapour and can be pressurised.

A typical design of open channel distributor has two sections, a primary distributor in fluid communication with a secondary distributor. The primary distributor reduces the velocity of the incoming liquid and evens out the flow. It may be in two-way fluid communication with the secondary distributor. The secondary distributor is responsible for the final distribution of the liquid, for example, on to the packing of the column of an ASU. All parts of the secondary

distributor are in two-way fluid communication with each other. The liquid usually leaves the distributor via one or more apertures and relies solely on liquid head, i.e. gravity, to make the liquid flow. To achieve uniform distribution, the liquid head must be substantially constant when flow division occurs, especially in the secondary distributor above the final distribution points.

In practice, there is always a slight hydraulic gradient along the distributor in order for the liquid to flow from one point to another. Distribution points at the outer edges of the secondary distributor, furthest from the liquid entry point, have slightly less head then those points nearer the middle. This difference can be significant on very large columns. In addition, if the distributor is not in horizontal alignment, non-uniform distribution of the liquid will be observed.

In typical ASUs, the accuracy of liquid distribution required is very high, often less than a 5% standard deviation across the distributor, in order to obtain high purity products from thermodynamically difficult separations. This results in a need to build expensive high quality distributors. However, some off-shore as well as land-based applications could require only low purity products and, thus, the separation becomes thermodynamically easier and the quality of liquid distribution is not as critical.

When an open channel distributor is not mounted horizontally or is mounted in a moving plane, for example onboard a ship, then the liquid distribution will vary as the distributor moves out of horizontal alignment. In this situation, the liquid is not evenly distributed within the distributor. On a large column, this can cause a significant change in the uniformity of distribution, in particular at turndown when the level of liquid in the distributor is reduced and the resultant flow rates become more sensitive to motion or to a permanent tilt.

One way to mitigate this problem is to use a closed distributor and to use a pump to move the liquid through the distributor under pressure rather than use gravity. The higher pressure head from the pump reduces the impact of the change in liquid head due to gravity as the distributor tilts. However, the use of a

pump increases the capital and operating costs of the separation process, often requires a back-up pump and uses electricity in a possibly hazardous environment. Alternatively, the liquid head due to gravity can be increased by using a higher liquid level, thereby reducing the change in liquid head observed as the distributor tilts. However, this increases the distance between the distributor and the centre of rotation which magnifies the adverse effects of the motion of the sea on the liquid distributor. Therefore, a balance between these two factors needs to be reached. Further, available space is usually limited on board a ship or off-shore platform and, thus, the size of the apparatus is restricted.

A cryogenic distillation column is usually packed with structured packing. Typically, the packing consists of a plurality of corrugated, perforated sheets of metal which are arranged vertically in parallel throughout the column. However, it is known to pack a column in sections with each section consisting of a number of these packing sheets arranged vertically and in parallel but which, as a section, are orientated at an angle to a neighbouring column packing section. For example, US-A-5984282 (Armstrong *et al*; published on 16th November 1999) discloses a number of arrangements of structured packing for liquid-vapour contact columns. However, only one liquid distributor is disclosed for use with every arrangement of structured packing. In other words, the distributor is not designed with a specific arrangement of packing in mind. The distributor in question is that disclosed in US-A-6149136.

US-A-6149136 (Armstrong *et al*; published on 21st November 2001) discloses a liquid distributor comprising a header tank in fluid communication with rows of reservoir cells in a liquid distribution plate located above the structured packing of a ship-board cryogenic distillation column. The distribution plate is a circular disc covering the whole cross section of the column and has identical bores of square cross section formed therein in uniform criss-cross rows. Alternate bores (vapour riser passages) are open at both the top and bottom to permit free flow of vapour therethrough and the remaining bores (reservoir cells) are blind being closed at their bases except for a central hole permitting limited flow of liquid therethrough.

US-A-6338774 (Lehman; published on 15th January 2002) discloses an open liquid distributor for use with an air distillation column on a floating platform or a barge. The distributor works by distributing liquid from a point in a receptacle to a point on the packing of the column that is not in vertical alignment with the point in the receptacle. One of the embodiments of the distributor comprises a two-stage distribution configuration. The first stage is an upwardly opening receptacle having a number of openings in the bottom of the receptacle that are disposed in a single crown adjacent to the peripheral wall. At a lower level is located a second stage for local distribution of the liquid comprising a number of regularly spaced, upwardly opening secondary receptacles, each having a perforated bottom. Each secondary receptacle has a smaller diameter then the first stage receptacle and is supplied by two tubes, themselves supplied respectively by two diametrically opposed openings in the first stage receptacle. In this way, each secondary receptacle should continue to be supplied by the first stage receptacle irrespective of the inclination of the distributor.

There is a need for an improved distributor that is less costly to manufacture and is still effective in maintaining an acceptably uniform distribution of liquid while the distributor is moved out of horizontal alignment. The primary objective of the present invention is to distribute liquid in a sufficiently uniform manner, possibly under pressure, on to the top layer of packing such that an effective separation can be achieved despite movement or permanent tilt of the distributor. In addition, there is a need for an improved distributor for use with columns having awkward or complicated arrangements of multiple sections of structured packing. Another objective of the present invention is to distribute liquid in a sufficiently uniform manner, possibly under pressure, on to the top layer of such packing such that separation can be achieved regardless of the packing arrangement. In addition, it is desirable that the distributor has low capital and operating costs and is easy to build.

According to a first aspect of the present invention, there is provided apparatus comprising, in fluid communication, a liquid distributor and a liquid-

vapour separation column tiltable from the vertical, said liquid distributor comprising a primary distribution zone and at least one secondary distributor, said primary distribution zone being in fluid communication with the or each secondary distributor and the or each secondary distributor having a plurality of liquid distribution apertures providing said fluid communication between the liquid distributor and the column, said apparatus being characterised in that:

(i) the distance between the two apertures that are furthest apart in the or each secondary distributor (the "characteristic length") is such that the liquid distributor provides, at each angle of tilt, a standard deviation of liquid flow rates through the apertures of the or each secondary distributor that is less than a first predetermined maximum for all angles of tilt; and

(ii) the difference in flow rate between the aperture having maximum liquid flow and the aperture having minimum liquid flow in the or each secondary distributor at each angle of tilt is less than a second predetermined maximum for all angles of tilt,

said first and second predetermined maxima being determined by the required degree of liquid-vapour separation.

The liquid flow rate through a distribution aperture (with liquid above the aperture) may be calculated approximately using the following equation:

$$Q = A.C_D\sqrt{\frac{2.\delta\rho.h}{\rho}}$$

where Q = volumetric flow rate;

A = cross-sectional area of aperture;

C_D = aperture discharge coefficient;

$\delta\rho$ = difference between liquid and vapour density;

ρ = liquid density; and

h = height of liquid above aperture.

For a given plurality of apertures arranged in a pattern on a flat secondary distributor base, the value of "h" for each aperture will be different when the liquid distributor is tilted out of horizontal alignment and, thus, the rate of liquid flow will be different from one aperture to the next.

The quality of the distribution is directly related to the thermodynamic difficulty of separation, i.e. the dimensions of the or each second secondary distributor is such that the final distribution of liquid on to the packing is acceptable.

For a given liquid-vapour separation, two factors are important if the liquid distributor is to provide a sufficient quality of liquid distribution. These factors are:

(a) the standard deviation of liquid flow rates through the apertures across a secondary distributor is below a first predetermined maximum; and

(b) the difference between the minimum and maximum liquid flow rates through any two apertures of the secondary distributor is below a second predetermined maximum.

If the locations of the apertures are known, it is possible to calculate a maximum angle of tilt for the liquid distributor that results in both this standard deviation and this difference being kept below the relevant maximum figures. Therefore, given a maximum expected angle of tilt for the liquid distributor, the required standard deviation of liquid flow rates, the differences between the minimum and maximum liquid flow rates and the aperture pattern, it is possible to calculate the maximum distance that the two apertures that are furthest apart in the secondary distributor can be separated. This maximum distance is referred to as the "characteristic length" of the secondary distributor and effectively determines the maximum size of secondary distributor which can be used. The calculation is independent of the shape of the secondary distributor as it is only dependent on the relative location of the apertures.

The characteristic length "ℓ_c" may be calculated from the following equation:

$$\frac{Q_{i-j}}{Q_{ave}} = A.C_D\left(\sqrt{\frac{2.\delta\rho}{\rho}}\right)\left(\sqrt{h_i} - \sqrt{h_i - l_c.\sin\theta}\right)$$

where Q_{i-j} = difference in volumetric flow rate between holes i & j;
Q_{ave} =average flow through the holes; and
θ = angle of distributor tilt.

The standard deviation of all the apertures within the secondary distributor can be calculated by the equation:

$$std.dev. = \sqrt{\frac{\left[n\sum Q_i^2 - \left(\sum Q_i\right)^2\right]}{n^2}}$$

where n =number of apertures;

If the size of the or each secondary distributor is less than the characteristic length, the flow rate of all the streams leaving the distributor will be within the acceptable standard deviation of flows when the column is tilted. The acceptable standard deviation of flows is determined by the thermodynamic difficulty of the separation; some separations are more difficult than others and will require more uniform liquid distribution. This can be determined from the approach of the operating line to the equilibrium line for the separation being considered. Once the operating line intersects the equilibrium line the separation stops. Therefore, the standard deviation of the flows and the relative difference between any two apertures is acceptable when the gradient of the operating line can be changed by that amount but would not result in the operating line crossing the equilibrium line.

Typically, air separation requires highly uniform distribution but for offshore and some land-based applications, the quality or recovery rate of products can be relaxed. By carefully matching the quality of liquid distribution to the specific separation conditions, it is possible to reduce the need for high quality distribution. As long as the characteristic length is selected such that, when the distributor is tilted or in motion, the standard deviation of flows from the distributor is acceptable, then the separation will be acceptably efficient despite some loss in separation due to a mismatch in liquid and vapour flow rates at various points across the packing.

The total cross-sectional area of said primary distribution zone defined by the outer periphery thereof is preferably less than the corresponding total cross-sectional area of the secondary distributor(s). The cross sectional area of a primary distributor is small relative to cross sectional area of the or each secondary distributor and thus regulates the flow to the or each secondary distributor well even when tilted or in motion. The use of a low profile design reduces the volume in the distributor, thereby reducing the stresses on the distributor due to the reduced mass of liquid contained therein. The design is easily scalable from small to large column diameters.

The "cross sectional area" of the primary and secondary distributors is the total cross sectional area as defined by the outer periphery thereof including any sections that have been removed to provide vapour flow paths. In other words, the cross sectional area of the primary or of the or each secondary distributor is the area of the region defined by the principle dimensions of the base of the distributors.

The primary distribution zone may comprise two or more primary distributors but, preferably, it comprises one primary distributor. The depth of a primary distributor is preferably more than the depth of the or each secondary distributor. The degree to which the amount of liquid head is affected by tilting the liquid distributor is less in a long, narrow primary distributor than it is in a shorter, wider primary distributor. The preferred arrangement is, therefore, a tall narrow

primary distributor combined with wider secondary distributor(s). The secondary distributor(s) must be wider in order to spread the liquid out over an area.

A primary distributor may not include any packing but, in preferred embodiments, it is at least partially filled with packing to dampen down liquid movement that may be induced by the motion of the distributor. The or each secondary distributor may also be at least partially filled with packing for the same reason. Where packing is used, the packing is usually random packing, although it is also possible to use structured packing.

Wherein the diameter of the column is no more than the characteristic length, said liquid distributor preferably comprises one secondary distributor. Whereas, where the diameter of the column is more than the characteristic length, liquid distributor preferably comprises a plurality of secondary distributors.

The secondary distributors on one side of the column could be connected to regulating apertures on the opposite side of the primary distributor thus helping to place slightly more liquid on the upper side of the column when the column is tilted but not in motion.

The liquid distributor may comprise a plurality of secondary distributors in an arrangement having a core secondary distributor surrounded by at least one ring of secondary distributors, said ring being concentric with the core secondary distributor. In another embodiment, the liquid distributor comprises a plurality of secondary distributors in a "chess board" arrangement.

The liquid distribution apertures are preferably arranged in a plurality of lines and the or each secondary distributor further comprises a liquid flow divider between at least two of said lines. For example, apertures may be located in the bottom of a channel in an open liquid distributor or in the bottom of a pipe or tube in a closed liquid distributor.

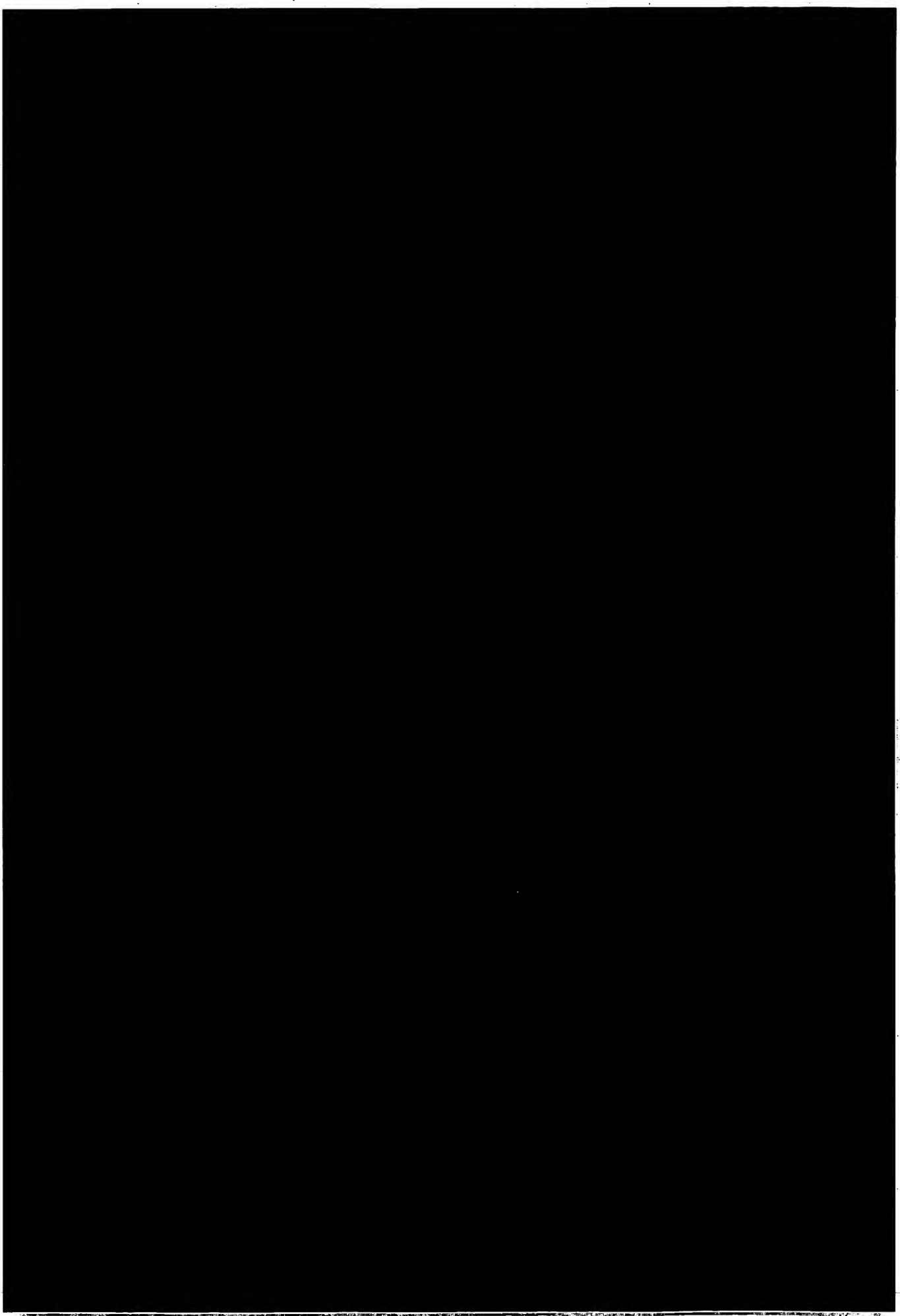
The or each secondary distributor preferably comprises a plurality of liquid distribution apertures distributed evenly about a base of thick plate material. The expression "thick plate material" is intended to refer to material having a thickness which is greater than the diameter of each aperture. Preferably, the material is at least twice as thick as the aperture diameter. Such thickness helps to keep the streams directed towards the desired point on the packing even when the distributor is tilted or in motion.

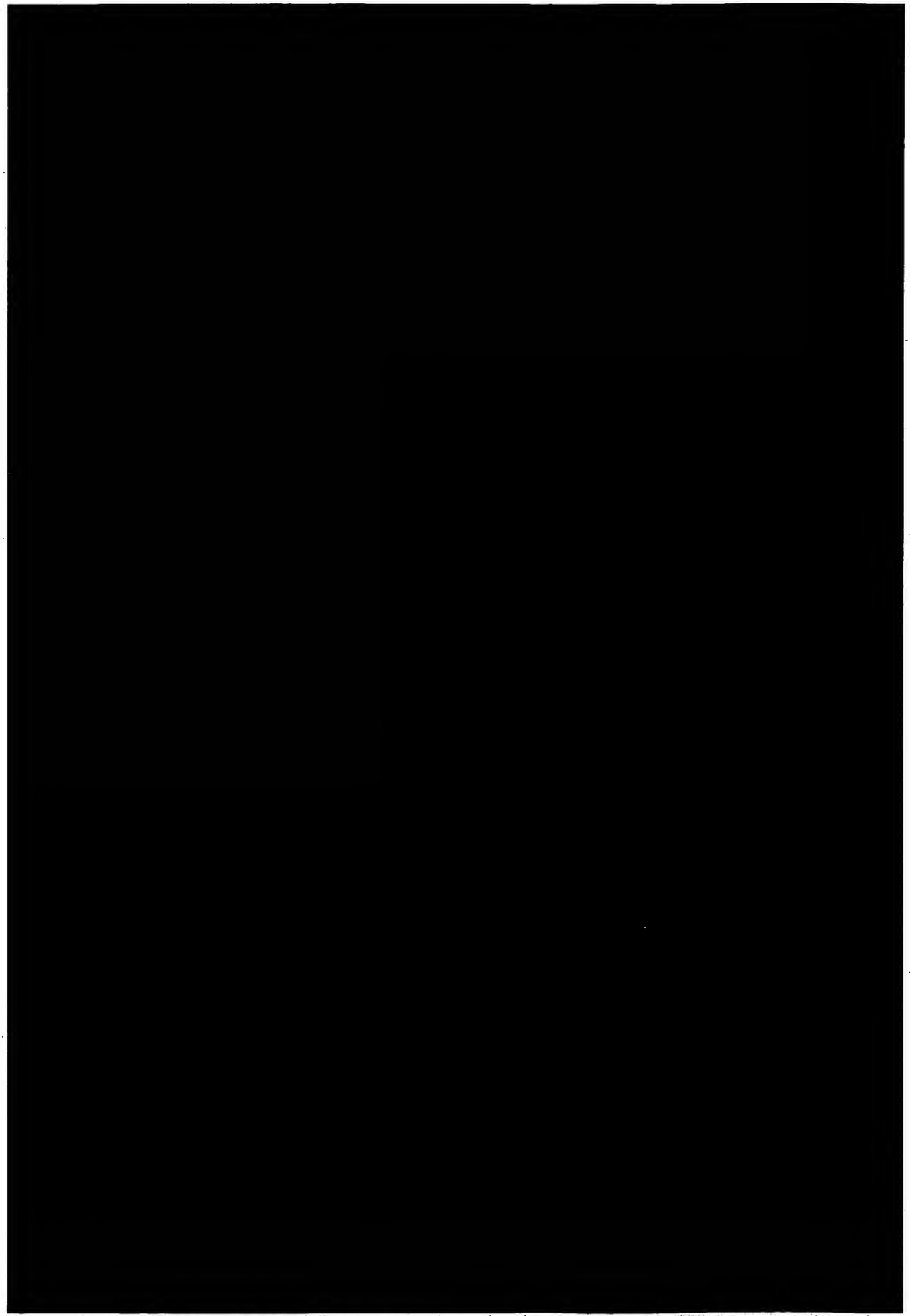
In a preferred embodiment, the liquid distributor has one secondary distributor having a receptacle comprising a base and a peripheral wall, the plurality of liquid distribution apertures being provided in the base. The secondary distributor provides at least one vapour flow path between the bottom and the top of the secondary distributor.

The or at least one secondary distributor may be divided into two or more compartments, each compartment being in fluid communication with each other compartment within said secondary distributor. In one embodiment, the secondary distributor may be substantially circular having a number of sectors, each sector being a compartment. The "secondary length" is the length of a compartment.

The or each secondary distributor comprises an arrangement of liquid distribution apertures which is preferably tailored to co-operate with a specific arrangement of structured column packing to improve liquid distribution. For example, where the column is packed with a plurality of vertical sheets of structured packing arranged in parallel, the liquid distribution apertures may be arranged in a plurality of parallel rows, said rows being orientated so as to traverse the planes of said packing sheets.

The or each secondary distributor is preferably fed from the primary distributor via a plurality of openings in the base of the primary distributor. The apertures are usually evenly distributed in a region of the primary distributor base and regulate flow of liquid from the primary distributor to the secondary





each secondary distributor and the or each secondary distributor having a plurality of liquid distribution apertures, said liquid distributor being characterised in that the total cross sectional area of said primary distributor zone defined by the outer periphery thereof is less than the corresponding cross sectional area of the or each secondary distributor. The liquid distributor may comprise any combination of features described above.

According to a third aspect of the present invention, there is provided an off-shore floating tiltable platform comprising apparatus that comprises, in fluid communication, a liquid distributor and a liquid-vapour separation column, said liquid distributor comprising a primary distribution zone and at least one secondary distributor, said primary distribution zone being in fluid communication with the or each secondary distributor and the or each secondary distributor has a plurality of liquid distribution apertures providing said fluid communication between the liquid distributor and the column, said platform being characterised in that:

(i) the distance between the two apertures that are furthest apart in the or each secondary distributor (the "characteristic length") is such that the liquid distributor provides, at each angle of tilt, a standard deviation of liquid flow rates through the apertures of the or each secondary distributor that is less than a first predetermined maximum for all angles of tilt; and

(ii) the difference in flow rate between the aperture having maximum liquid flow and the aperture having minimum liquid flow in the or each secondary distributor at each angle of tilt is less than a second predetermined maximum for all angles of tilt,

said first and second predetermined maxima being determined by the required degree of liquid-vapour separation. The apparatus may have any of the features described above.

The following is a description, by way of example only and with reference to the accompanying drawings, of presently preferred embodiments of the invention.

Figure 1 is a diagrammatic cross-sectional representation of a secondary distributor;

Figure 2 is a diagrammatic cross-sectional representation of an embodiment of the present invention designed to irrigate a column having a diameter about equal to the characteristic length of the secondary distributor;

Figure 3 is a representation of one possible liquid distributor according to Figure 2;

Figure 4 is a plan view of the base of the secondary distributor depicted in Figure 3.

Figure 5 is a diagrammatic cross-sectional representation of an embodiment of the present invention designed to irrigate a column having a diameter that is five times the characteristic length;

Figure 6A is a diagrammatic cross-sectional representation of an alternative arrangement of the embodiment depicted in Figure 5;

Figure 6B is a diagrammatic plan view of one possible liquid distributor according to Figure 6A;

Figure 7A is a diagrammatic cross-sectional representation of an embodiment of the present invention designed to irrigate a column having a diameter that is three times the characteristic length;

Figure 7B is a diagrammatic plan view of one possible liquid distributor according to Figure 7A;

Figure 8 is a diagrammatic representation of one possible base of the primary distributor in the embodiment depicted in Figures 7A and 7B; and

Figure 9 depicts three examples of different packing arrangements for a liquid-vapour separation column that show how the liquid distributor of the present invention can accommodate different packing arrangements.

Figure 1 depicts a secondary distributor 10 partially filled with a liquid 12 that is being distributed as a series of streams 14. The secondary distributor 10 is packed 16 to reduce the movement of the liquid 12 within the distributor. The characteristic length ("ℓ_c") may be defined as the distance between the two distribution apertures that are furthest apart in a secondary distributor such that the liquid distributor provides a standard deviation of liquid flow rates through the apertures of the secondary distributor that is less than a first maximum figure and

a difference between the maximum and minimum liquid flow rates through any two apertures of the secondary distributor that is less than a second maximum figure. The first and second maximum figures depend on and are determined by the required degree of vapour-liquid separation, the degree to which the column is tilted and the pattern of the apertures in the secondary distributor.

In Figure 2, a primary distributor 18 is in fluid communication with one secondary distributor 10. The primary distributor 18 is packed 20 to restrict the movement of the liquid 12 within the liquid distributor and is located within the column 22 which has a diameter of about the characteristic length of the secondary distributor 10.

Figure 3 depicts a liquid distributor 24 that would normally be used in combination with a ship-based liquid-vapour contact column where the column diameter is no more than the characteristic length of the secondary distributor 10. The liquid distributor 24 comprises a primary distributor 18 and one secondary distributor 10 having six compartments 26, each compartment 26 having a secondary length of about half of the characteristic length. The primary distributor 18 is in fluid communication with each compartment 26 of the secondary distributor 10 via a pipe 28. The liquid distributor 24 is positioned on the top layer of packing 30 of a cryogen distillation column (not shown). Each level of packing in the column consists of six equal sectors 32 arranged about the longitudinal axis of the column. Each sector 32 comprises a plurality of vertical sheets of structured packing material (not shown) arranged in parallel in tangential planes to the column axis. Each compartment 26 distributes liquid to one sector 32. The secondary distributor 10 comprises an arrangement of channels 34 that are covered, each channel 34 having an arrangement of apertures 36 in the base 38 of the secondary distributor 10. These apertures are arranged in a number of rectilinear lines extending radially from the column axis and traverse the planes of the packing sheets in the sector supplied by that compartment 26 of the secondary distributor 10. Rising vapour vents (not shown) would be needed if the liquid distributor and column formed a closed system.

Liquid is fed into the primary distributor 18 which reduces the velocity of the liquid and evens out the flow. From the primary distributor 18, liquid flows into the channels 34 of each compartment 26 of the secondary distributor 10 via pipes 28. The liquid then flows out from the secondary distributor 10 via the apertures 36 and on to the top layer of packing 30. The rate of flow from the apertures 36 is substantially equal across the whole liquid distributor 24 when the distributor 24 is in horizontal alignment and the standard deviation of flow rate across the distributor is such that effective separation is still possible even while the distributor is being tilted and moved by the motion of the sea.

Figure 4 depicts the arrangement of apertures 36 in the base 38 of the secondary distributor 10 of the liquid distributor 24 in Figure 3. The apertures 36 are arrayed in a plurality of rectilinear lines extending radially from the centre of the secondary distributor 10.

Figure 5 depicts a liquid distributor 24 for use with a column 22 having a diameter that is about five times the characteristic length of a secondary distributor 10. The liquid distributor comprises a primary distributor 18 located within the column 22 and multiple secondary distributors 10.

Figure 6A depicts an alternative arrangement for the liquid distributor 24 shown in Figure 5. In this arrangement, the primary distributor 18 is located outside the column 22. A plan view of a liquid distributor 24 conforming to this alternative arrangement is depicted in Figure 6B. The liquid distributor 24 comprises one primary distributor 18, located outside the column, in fluid communication (not shown) with twenty-one secondary distributors 10 arranged in a "chess-board" configuration.

Figure 7A depicts a liquid distributor 24 for use with a column 22 having a diameter that is about three times the characteristic length of a secondary distributor 10. The liquid distributor 24 comprises a primary distributor 18 located within the column 22 and multiple secondary distributors 10.

Figure 7B depicts a plan view of a liquid distributor 24 conforming to the arrangement depicted in Figure 7A. The liquid distributor 24 comprises one primary distributor 18, located inside the column, in fluid communication (not shown) with nine secondary distributors 10, eight of which being arranged in a ring about a core secondary distributor.

A base 40 of a primary distributor 18 (that could be used in the liquid distributor 24 depicted in Figures 7A and 7B) is depicted in Figure 2. Fluid passes from the primary distributor 18, through an array of regulating apertures 42 and into one of the pipes 28. The apertures 42 regulate the flow of the liquid to the secondary distributors (not shown).

Figure 9 depicts three arrangements of structured packing for a liquid-vapour separation column. A column can be packed in a single section (e.g. B) or can be packed in multiple sections (e.g. A and C). The liquid distributor of the present invention has particular application in combination with columns packed in multiple sections and such a combination is particularly effective in ship-board applications.

Example 1

The standard deviation of flow rate has been calculated for a conventional design of liquid distributor (40mm by 80mm hole pitch; one primary distributor and one secondary distributor) used in combination with a 1.0m column and a 4.4m column tilted to 1° and 4°. The results are shown in Table 1.

If the nature of the separation is such that the optimum flow distribution (for all flows) is to be within +/- 4% of the ideal, then the results indicate that, as the liquid distributor is tilted, the maximum and minimum flow rates are significantly outside this criteria for the large liquid distributor at turndown and only marginally inside at full flow.

Table 1

	Tilt Angle = 1°	Tilt Angle = 4°	Tilt Angle = 1°	Tilt Angle = 4°
Diameter	1.0m	1.0m	4.4m	4.4m
Full flow				
Std. Dev.,	0.2%	0.9%	1.0%	3.9%
Max Flow	+0.4%	+1.6%	+1.9%	+7.3%
Min Flow	-0.4%	-1.7%	-1.9%	-7.9%
Turndown				
Std. Dev.	0.4%	1.8%	1.9%	7.8%
Max Flow	+0.8%	+3.2%	+3.7%	+14.1%
Min Flow	-0.8%	-3.4%	-3.9%	-16.4%

The standard deviation of liquid low rate has also been calculated for a liquid distributor of the present invention having a characteristic length of less than 1.0m and the results are shown in Table 2.

Table 2

	Tilt Angle = 1°	Tilt Angle = 4°	Tilt Angle = 1°	Tilt Angle = 4°
Diameter	1.0m	1.0m	4.4m	4.4m
Characteristic Length	0.96m	0.96m	0.96m	0.96m
Full flow				
Std. Dev.	0.2%	0.9%	0.2%	0.9%
Max Flow	+0.4%	+1.6%	+0.4%	+1.6%
Min Flow	-0.4%	-1.7%	-0.4%	-1.7%
Turndown				
Std. Dev.	0.4%	1.7%	0.4%	1.7%
Max Flow	+0.8%	+3.2%	+0.8%	+3.2%
Min Flow	-0.8%	-3.3%	-0.8%	-3.3%

Assuming the same nature of the separation as for the conventional distributor (such that the optimum flow distribution (for all flows) is to be within +/- 4% of the ideal), then the results indicate that, as the liquid distributor is tilted, the maximum and minimum flow rates are well inside the acceptable +/- 4% deviation at both full flow and turndown. The standard deviation for a 4.4m column is essentially that of a 1.0m column when the new design of distributor is used. This

is because the secondary distributors are isolated from each other and so act as though they are irrigating a smaller column.

Example 2

A test rig comprising a liquid distributor (as shown in Figure 3) having a primary distributor in fluid communication with one secondary distributor (having a characteristic length of 1.0m and a secondary length of about 0.5m) was constructed and tested using water as the liquid to be distributed. The liquid distributor was designed to be used with a column having a diameter of 1.0 m and the diameter of the primary distributor was 0.2m.

The liquid distributor was observed to provide a substantially uniform distribution of liquid across the entire flow area of the column. The results of Example 2 correlate with the calculations of Example 1 for the 1.0m column.

In the preferred embodiment, the distributor is substantially enclosed (except for the required vapour vents). The use of random packing to dampen down liquid movement within the distributor helps prevent liquid turbulence affecting the flow through the apertures.

It will be appreciated that the invention is not restricted to the details described above with reference to the preferred embodiments but that numerous modifications and variations can be made without departing from the scope of the invention as defined in the following claims.

CLAIMS

1. Apparatus for liquid-vapour separation processes, said apparatus comprising, in fluid communication, a liquid distributor and a liquid-vapour separation column tiltable from the vertical, said liquid distributor comprising a primary distribution zone and at least one secondary distributor, said primary distribution zone being in fluid communication with the or each secondary distributor and the or each secondary distributor having a plurality of liquid distribution apertures providing said fluid communication between the liquid distributor and the column, said apparatus being characterised in that:

(i) the distance between the two apertures that are furthest apart in the or each secondary distributor (the "characteristic length") is such that the liquid distributor provides, at each angle of tilt, a standard deviation of liquid flow rates through the apertures of the or each secondary distributor that is less than a first predetermined maximum for all angles of tilt; and

(ii) the difference in flow rate between the aperture having maximum liquid flow and the aperture having minimum liquid flow in the or each secondary distributor at each angle of tilt is less than a second predetermined maximum for all angles of tilt,

said first and second predetermined maxima being determined by the required degree of liquid-vapour separation.

2. Apparatus as claimed in Claim 1 wherein the characteristic length (ℓ_c) is calculated according to the following equation:

$$\frac{Q_{i-j}}{Q_{ave}} = A.C_D\left(\sqrt{\frac{2.\delta\rho}{\rho}}\right)\left(\sqrt{h_i} - \sqrt{h_i - l_c.\sin\theta}\right)$$

where Q_{i-j} = difference in volumetric flow rate between apertures i & j;

Q_{ave} =average flow through the apertures;

A = cross-sectional area of aperture;

C_D = aperture discharge coefficient;

$\delta\rho$ = difference between liquid and vapour density;

ρ = liquid density; and

h = height of liquid above aperture.

θ = angle of distributor tilt.

3. Apparatus as claimed in Claim 1 or Claim 2 wherein the total cross-sectional area of said primary distribution zone defined by the outer periphery thereof is less than the corresponding total cross-sectional area of the secondary distributor(s).

4. Apparatus as claimed in any of the preceding claims wherein the diameter of the column is no more than the characteristic length, said liquid distributor comprising one secondary distributor.

5. Apparatus as claimed in any of Claims 1 to 3 wherein the diameter of the column is more than the characteristic length, said liquid distributor comprising a plurality of secondary distributors.

6. Apparatus as claimed in any of the preceding claims wherein the column is packed in a plurality of sections and the liquid distributor has a separate secondary distributor provided for distributing fluid to each section.

7. Apparatus as claimed in any of Claims 1 to 5 wherein the column is packed in a plurality of sections and the or each secondary distributor is provided to distribute fluid to more than one section.

8. Apparatus as claimed in any of the preceding claims wherein the liquid distributor comprises a plurality of secondary distributors in an arrangement having a core secondary distributor surrounded by at least one ring of secondary distributors, said ring being concentric with the core secondary distributor.

9. Apparatus as claimed in any of Claims 1 to 7 wherein the liquid distributor comprises a plurality of secondary distributors in a "chess board" arrangement.

10. Apparatus as claimed in any of the preceding claims wherein the primary distribution zone is at least partially filled with packing.

11. Apparatus as claimed in any of the preceding claims wherein the or each secondary distributor is at least partially filled with packing.

12. Apparatus as claimed in Claim 10 or Claim 11 wherein the packing is selected from the group consisting of random packing and structured packing.

13. Apparatus as claimed in any of the preceding claims wherein the liquid distribution apertures are arranged in a plurality of lines, the or each secondary distributor further comprising at least one liquid flow divider between at least some of said lines.

14. Apparatus as claimed in any of the preceding claims wherein the or each secondary distributor has a base having a thickness that is greater than the diameter of each liquid distribution aperture.

15. Apparatus as claimed in Claim 14 wherein the thickness of the base is at least twice the diameter of each liquid distribution aperture.

16. Apparatus as claimed in any of the preceding claims wherein the or at least one secondary distributor is divided into two or more compartments, each compartment being in fluid communication with each other compartment within said secondary distributor.

17. Apparatus as claimed in Claim 16 wherein the secondary distributor is substantially circular having a number of sectors, each sector being a compartment.

18. Apparatus as claimed in any preceding claim wherein the column is packed in sectors about the longitudinal axis of the column, each sector comprising a plurality of vertical sheets of structured packing arranged in parallel in tangential planes to the column axis and the liquid distribution apertures are arranged in a plurality of rectilinear lines extending radially from the column axis, said lines traversing the planes of said packing sheets.

19. Apparatus as claimed in any of the preceding claims wherein the primary distribution zone comprises one primary distributor.

20. Apparatus as claimed in Claim 19 wherein the or each secondary distributor is fed from the primary distributor via a plurality of openings in the base of the primary distributor, said openings being evenly distributed in a region of the primary distributor base.

21. Apparatus as claimed in Claim 19 or Claim 20 wherein the primary distributor is located outside the column.

22. Apparatus as claimed in any of the preceding claims wherein said liquid distributor is a closed system.

23. Apparatus as claimed in any of the preceding claims wherein the total cross sectional area of the secondary distributor(s) is from 60% to 95% of the total cross sectional area of the column with the remaining area being substantially taken up by vapour vents.

24. Apparatus as claimed in Claim 23 wherein the total cross sectional area of the secondary distributor(s) is about 90% of the cross sectional area of the column with the remaining area being substantially taken up by vapour vents.

25. Apparatus as claimed in any of the preceding claims wherein the liquid distributor comprises one secondary distributor, said secondary distributor being an integral part of the primary distribution zone.

26. Apparatus as claimed in any one of the preceding claims adapted and/or constructed for cryogenic distillation.

27. Apparatus as claimed in any of the preceding claims *in situ* on a ship or other off-shore floating platform.

28. A liquid distributor for use in liquid-vapour separation processes, said liquid distributor comprising a primary distributor zone and at least one secondary distributor, said primary distributor zone being in fluid communication with the or each secondary distributor and the or each secondary distributor having a plurality of liquid distribution apertures, said liquid distributor being characterised in that the total cross sectional area of said primary distributor zone defined by the outer periphery thereof is less than the corresponding cross sectional area of the or each secondary distributor.

29. A liquid distributor as claimed in Claim 28 comprising the features of the liquid distributor as defined in any one of Claims 2 to 27.

30. An off-shore floating tiltable platform comprising apparatus that comprises, in fluid communication, a liquid distributor and a liquid-vapour separation column, said liquid distributor comprising a primary distribution zone and at least one secondary distributor, said primary distribution zone being in fluid communication with the or each secondary distributor and the or each secondary distributor has a plurality of liquid distribution apertures providing said fluid communication between the liquid distributor and the column, said platform being characterised in that:

(i) the distance between the two apertures that are furthest apart in the or each secondary distributor (the "characteristic length") is such that the liquid distributor provides, at each angle of tilt, a standard deviation of liquid flow rates through the apertures of the or each secondary distributor that is less than a first predetermined maximum for all angles of tilt; and

(ii) the difference in flow rate between the aperture having maximum liquid flow and the aperture having minimum liquid flow in the or each secondary distributor at each angle of tilt is less than a second predetermined maximum for all angles of tilt,

said first and second predetermined maxima being determined by the required degree of liquid-vapour separation.

31. An off-shore floating platform as claimed in Claim 30 comprising apparatus as defined in any of Claims 2 to 26.

ABSTRACT

A LIQUID DISTRIBUTOR

Liquid is distributed substantially uniformly in a liquid-vapour separation column located on an off-shore floating platform such as a ship using a liquid distributor comprising a primary distribution zone and at least one secondary distributor, the primary distribution zone being in fluid communication with the or each secondary distributor and the or each secondary distributor having a plurality of liquid distribution apertures providing said fluid communication between the liquid distributor and the column. The liquid distributor is characterised in that:

(i) the distance between the two apertures that are furthest apart in the or each secondary distributor (the "characteristic length") is such that the liquid distributor provides, at each angle of tilt, a standard deviation of liquid flow rates through the apertures of the or each secondary distributor that is less than a first predetermined maximum for all angles of tilt; and

(ii) the difference in flow rate between the aperture having maximum liquid flow and the aperture having minimum liquid flow in the or each secondary distributor at each angle of tilt is less than a second predetermined maximum for all angles of tilt,

said first and second predetermined maxima being determined by the required degree of liquid-vapour separation. One advantage of such a liquid distributor is that liquid can be distributed substantially uniformly when the column is tilted.

(Figure 3)

[redacted]

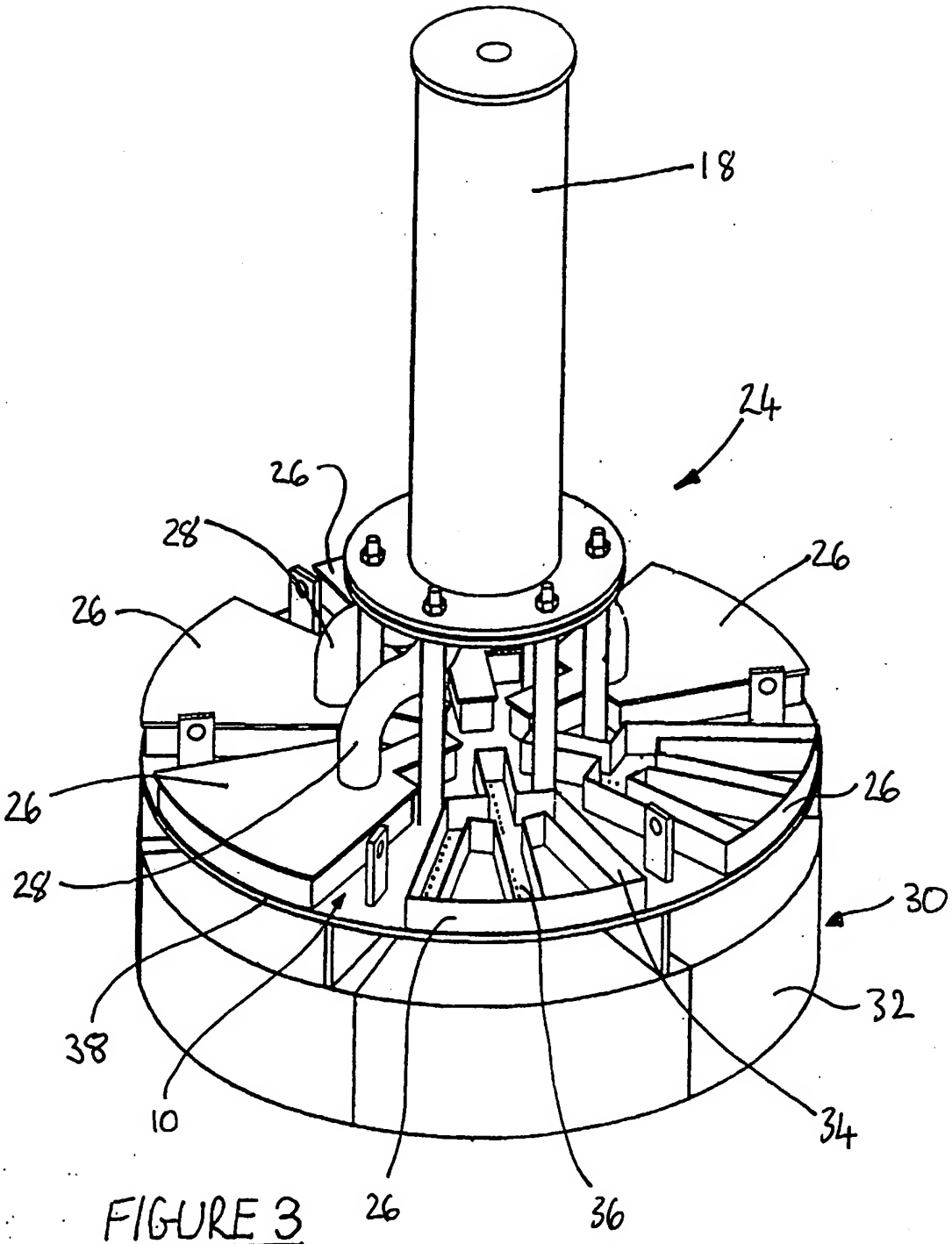


FIGURE 3

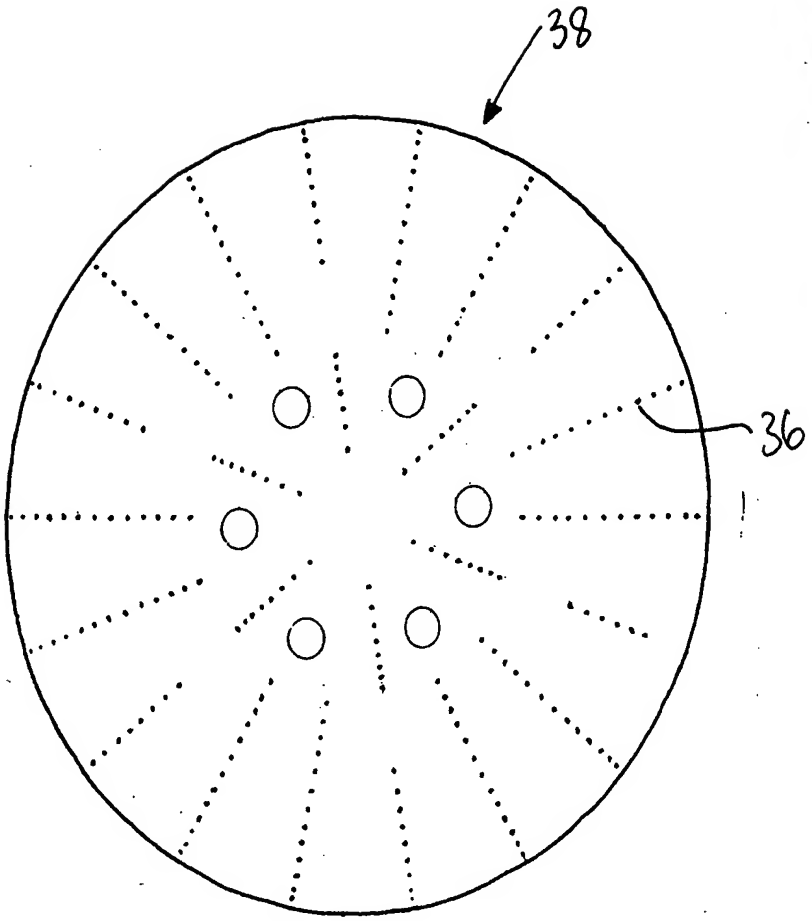


FIGURE 4

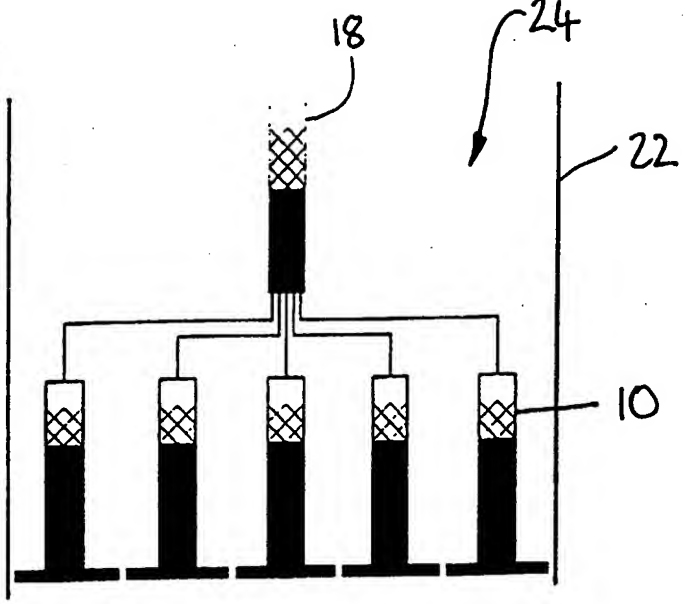


FIGURE 5

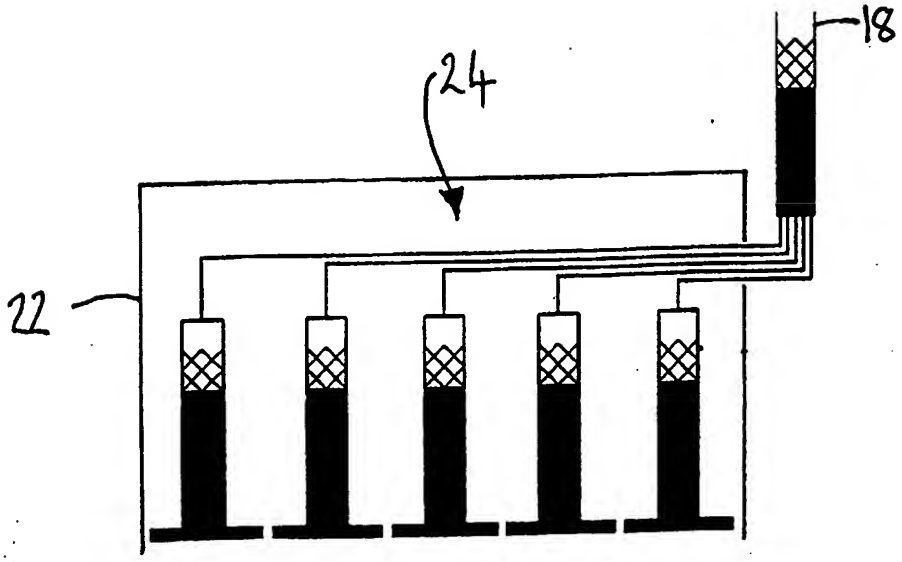


FIGURE 6A

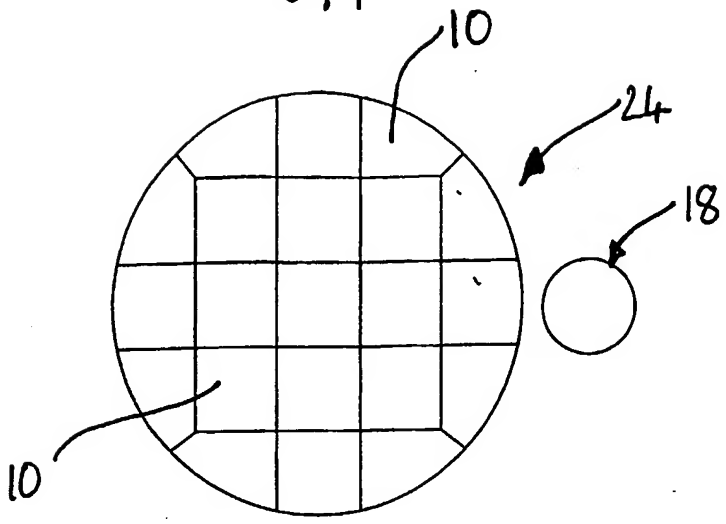


FIGURE 6B

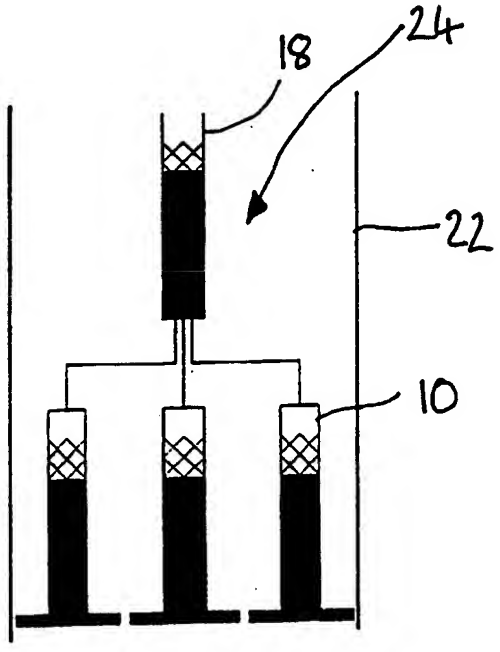


FIGURE 7A

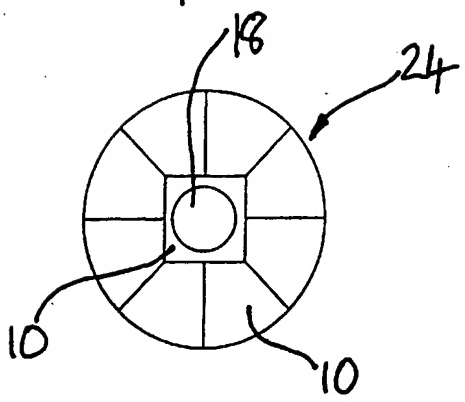


FIGURE 7B

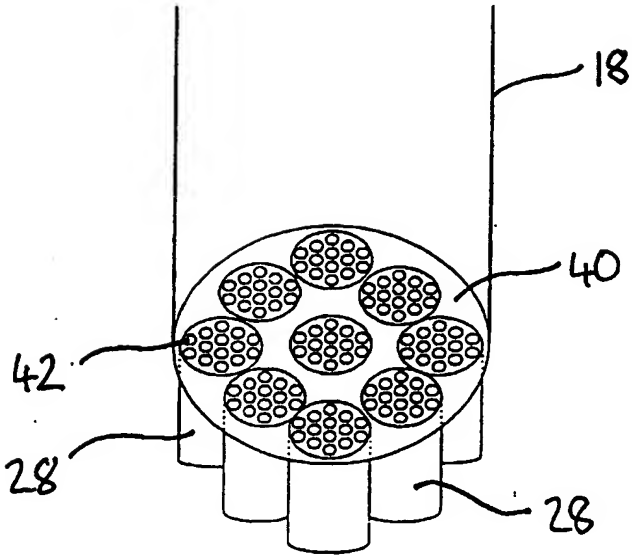


FIGURE 8

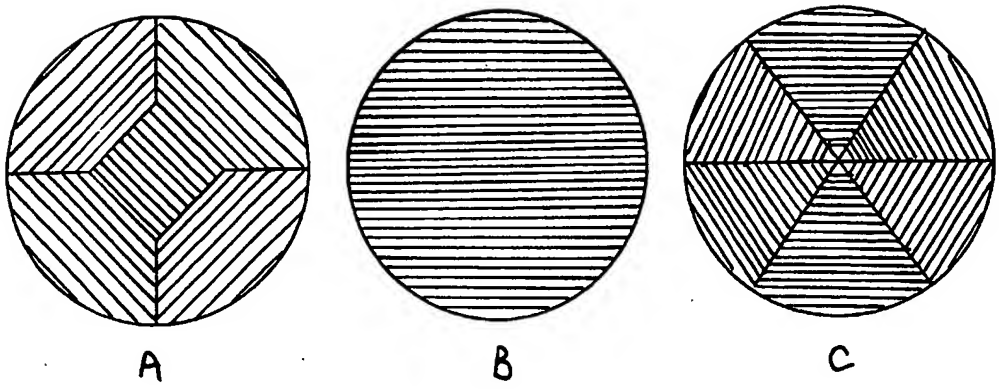


FIGURE 9

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